Population Ecology

Chapter 53
Populations

A **population** consists of individuals of a given species living together at the same place at the same time.

*Tetraphis pellucida* (moss)
You are looking at the *Tetraphis* moss distribution at different scales.

Exercise: How do you define a population for the *Tetraphis* moss?
It’s up to you. You can call any of these circle a population.

Metapopulation: a population of the *Tetraphis* moss populations
Population ecology deals with

- Distribution of populations
  - the spatial variations of populations (range of the species and dispersion of individuals)

- Abundance of populations
  - the temporal variations of populations (number of individuals, demography, temporal dynamics)

Most species have limited ranges

![Map of species with limited ranges](image)
Devil’s Hole pupfish live in a desert spring

*C. diabolis* only live in Devil’s hole, Nevada.
Iriomote cat only live on the Iriomote Island of Japan

Only a few species are globally common
Factors that limit distribution (analysis of presence/absence)

1. **Accessibility (dispersal ability)**
2. Limitation by physical-chemical factors
3. Biological interactions w/ other species

Dispersal ability can determine population distribution

- Windblown fruits
  - *Asclepias syriaca*
  - *Acer saccharum*
  - *Terminalia calamansain*
- Adherent fruits
  - *Medicago polycarpa*
  - *Bidens frondosa*
  - *Ranunculus muricatus*
- Fleshy fruits
  - *Solanum dulcamara*
  - *Juniperus chinensis*
  - *Rubus sp.*
Human facilitated dispersal

- Humans have allowed some species to expand their ranges by moving species around.
- The overall effect has often been detrimental.
Zebra mussels in North America

Rapid range expansion
Zebra mussels block water pipes

Red imported fire ant
Red imported fire ants in Taiwan

Fire ant damages
Population distribution –
What is the pattern of dispersion?

- **Clumped** dispersion is when individuals aggregate in patches.
- **Uniform** dispersion is when individuals are evenly spaced.

- In **random** dispersion, the position of each individual is independent of the others.
Exercise: What factors contribute to each pattern of dispersion?

Factors that limit distribution (analysis of presence/absence)

1. Accessibility (dispersal ability)
2. Limitation by physical-chemical factors
3. Biological interactions w/ other species
Factors that affect abundance
(analysis of high/low density)

1. Limitation by physical-chemical factors
2. Biological interactions w/ other species

Physical-chemical factors

- Key elements of an organism’s environment include:
  - temperature
  - moisture
  - sunlight
  - nutrients
  - .....
Responses to Environmental Change

- Short-term responses
  - Physiology (homeostasis)
  - Morphology (fur thickness, etc.)
  - Behavior (basking, dewing, etc.)
- Evolutionary responses (adaptation)
  - Physiology (water conservation, etc.)
  - Morphology (Allen’s Rule, Bergmann’s Rule)
  - Behavior (migration, dormant, etc.)
- Range shift

Short-term morphological responses (fur thickness)
Short-term behavioral responses (change habitats)

Temperature (basking)
Moisture (dewing)

Evolutionary adaptation (Allen’s rule)

Allen’s rule in hares -- extremities
Evolutionary adaptation (Bergmann’s rule)

Bergmann’s rule in bears
– body sizes

Range shift

Elevation (km)

- 3 km
- 2 km
- 1 km
- 0 km

- Alpine tundra
- Spruce-fir forests
- Mixed conifer forest
- Woodlands
- Grassland, chaparral, and desert scrub

15,000 years ago

Present
Biological interactions

- Competition
- Predation (Exploitation)
  - Carnivory
  - Herbivory
  - Parasitism (& Disease)
  - Insect Parasitoidism
- Mutualism

Competition

*Chthamalus*
*Balanus*

Ocean
Carnivory

Herbivory
Parasitism

Insect Parasitoid
Mutualism

Population abundance – How many buffaloes are there?
Mark-recapture method

- Individuals are captured in an area, marked, and then released.
- After a period of time has elapsed, individuals are captured again and marked individuals identified.
- Population size is estimated based on recapture probability of marked individuals.

Exercise: Mark-recapture method

- 10 mice are captured in an area, marked, and then released.

- After a period of time has elapsed, 10 mice are captured again, including 5 marked individuals.

- Please estimate the population size.
Population abundance

- Population growths are functions of birth, death, immigration, and emigration (i.e. $\Delta N = B - D + I - E$).

- Changes in any of those parameters will potentially change population size.

A life table (a survivorship table)

<table>
<thead>
<tr>
<th>Age (in 3-month intervals)</th>
<th>Number Alive at Beginning of Time Interval</th>
<th>Proportion of Cohort Surviving to Beginning of Time Interval (survivorship)</th>
<th>Deaths During Time Interval</th>
<th>Mortality Rate During Time Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>843</td>
<td>1.000</td>
<td>121</td>
<td>0.143</td>
</tr>
<tr>
<td>1</td>
<td>722</td>
<td>0.857</td>
<td>195</td>
<td>0.271</td>
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<tr>
<td>2</td>
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<td>211</td>
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<tr>
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<td>172</td>
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<tr>
<td>6</td>
<td>15</td>
<td>0.018</td>
<td>12</td>
<td>0.800</td>
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<td>7</td>
<td>3</td>
<td>0.004</td>
<td>3</td>
<td>1.000</td>
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<tr>
<td>8</td>
<td>0</td>
<td>0.000</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
Survivorship curve

- It is a plot of the number of individuals in a cohort still alive at each age.
  - A Type I curve shows a high survival rate early in life (human).
  - The Type II curve shows constant survival rate (hydra).
  - Type III curve shows a low survival rate early in life (oyster).
Exercise: What type of survivorship curve is it?

<table>
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<td>1.000</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0.000</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Survivorship curve for *Poa*
Let's add a reproductive table

<table>
<thead>
<tr>
<th>Age (in 3-month intervals)</th>
<th>Seeds Produced During Time Interval</th>
<th>Seeds Produced per Surviving Individual (fecundity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>1</td>
<td>303</td>
<td>0.42</td>
</tr>
<tr>
<td>2</td>
<td>622</td>
<td>1.18</td>
</tr>
<tr>
<td>3</td>
<td>450</td>
<td>1.36</td>
</tr>
<tr>
<td>4</td>
<td>210</td>
<td>1.46</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>1.11</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>2.00</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>3.33</td>
</tr>
<tr>
<td>8</td>
<td>Total = 1665</td>
<td></td>
</tr>
</tbody>
</table>

The 2 tables together give population growth rate

<table>
<thead>
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<th>Age (in 3-month intervals)</th>
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<th>Mortality Rate During Time Interval</th>
<th>Seeds Produced During Time Interval</th>
<th>Seeds Produced per Surviving Individual (fecundity)</th>
<th>Seeds Produced per Member of Cohort (fecundity × survivorship)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>843</td>
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<td>121</td>
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<td>195</td>
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<td>x</td>
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<td>0.42 0.36</td>
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<td>0.400</td>
<td>622</td>
<td>1.18</td>
<td>0.74 0.51</td>
</tr>
<tr>
<td>3</td>
<td>316</td>
<td>0.375</td>
<td>172</td>
<td>0.544</td>
<td>430</td>
<td>1.36</td>
<td>0.25 0.14</td>
</tr>
<tr>
<td>4</td>
<td>144</td>
<td>0.171</td>
<td>90</td>
<td>0.626</td>
<td>210</td>
<td>1.46</td>
<td>0.07 0.11</td>
</tr>
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<td>39</td>
<td>0.722</td>
<td>60</td>
<td>1.11</td>
<td>0.04 0.07</td>
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<td>0.800</td>
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<td>2.00</td>
<td>0.01 0.07</td>
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</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0.000</td>
<td></td>
<td></td>
<td>1665</td>
<td>Total = 1665</td>
<td></td>
</tr>
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</table>
### Exercise: Is this population increasing or declining?

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<td>10</td>
<td>3.33</td>
<td>0.01</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0.000</td>
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<td></td>
<td>Total = 1,665</td>
<td>Total = 1.98</td>
<td></td>
</tr>
</tbody>
</table>

### Life table & Life history

- A life history is the life cycle of an organism.

- An organism’s schedule of survivorship and reproduction affect its life history.

- Life history often involve significant trade-offs.

- Natural selection favor the life history that maximizes lifetime reproductive success.
Some life history trade-offs

- Increase current reproduction may decrease survival and chances of future reproduction (cost of reproduction).

- Increase the number of offspring produced may decrease the amount of resources invested in any single offspring, thus critically affects chances of survival (quality vs quantity).
Cost of reproduction (reduced future reproduction)

Cost of reproduction in birds
Quantity vs quality

![Graph showing the relationship between clutch size and nestling size (weight in grams). The graph illustrates a decrease in nestling size as clutch size increases.](image)
Different life-history strategies

- Reproductive events per lifetime
  - semelparity - organisms focus all reproductive efforts on a single, large event
  - iteroparity - organisms produce offspring several times over many seasons

- Age at first reproduction
  - Longer-lived animals tend to reproduce later, and provide more parental care than shorter-lived animals.

Semelparity
Exercise:
What factors contribute to the evolution of semelparity and iteroparity?

Exercise: population growth

• Let’s assume the life table of fruit flies is: each female lay all 20 eggs (1:1 sex ratio) as soon as they reach adulthood. It takes 2 weeks from egg to adult.

• Put a pair of fruit flies in a vial, how long does it take to reach 200,000,000,000,000,000,000,000,000,000,000 flies? (assuming ideal condition & no death)
ONLY ONE YEAR

If you line them up head to tail, it’d get you beyond the solar system.

Population growth

- If population increases in 2 - 4 – 6 – 8 – 10 – 12 -....... , it’s an arithmetic growth. (adding)

- If population increases in 2 – 4 – 8 – 16 – 32 – 64 -....... , it’s an exponential growth. (multiplying)
• The fruit flies we mentioned live in an ideal world. It showed an exponential population growth (J-shaped growth).
• The flies have high “biotic potential”
  \[\frac{b-d}{\text{per individual’s potential}}.\]
Exercise: Which species has a greater biotic potential? Why?
The change in population size over time.

Under ideal condition, each species has a characteristic rate, \( r \). The ‘Intrinsic capacity for growth’ is a measure of a population’s potential for growth (biotic potential).

Generation time is an important factor affecting \( r \).

E. coli has a high innate capacity for growth (\( r \)).
An exponential (J-shape) population growth

A J-shape population growth

Significant advances in medicine through science and technology
Industrial Revolution
Bubonic plague "Black Death"
For species with overlapping generations, population growth occurs continuously. We use calculus to mimic the “change in population size that occurs during a very small interval of time”.

\[
\frac{dN}{dt} = r \times N
\]

- \( r \) = the ‘Intrinsic capacity for growth’ (biotic potential, \( r_{max} \)).
- \( N \) = population size

Populations can’t grow indefinitely
Carrying capacity

- Carrying capacity \((K)\) is the maximum number of individuals the resources in a given area can support.

Influence of Population Density

As a population approaches its \(K\), environmental factors can become severe, leading to decreased birth rate \((b)\) and increased death rate \((d)\), thus decreased \((r)\). The growth of population slows down, and eventually stop as the population reaches carrying capacity.

- Because the population size stabilizes, this is called density-dependent population control.
Density-dependent $r$

1. Let’s say, a population has a $K$, where $r = 0$.

2. Let $r$ decreases as population size ($N$) increases, and define $r_{\text{realized}} = r_{\text{max}} \cdot (K-N)/K$.

Density dependent $r$

- Define $r_{\text{realized}} = r_{\text{max}} \cdot (K-N)/K$.
- The population growth equation becomes

\[
\frac{dN}{dt} = r \cdot \frac{K - N}{K} \cdot N
\]
As population growth rate slows down, and reaches zero at **carrying capacity**, that would give population an S-shaped growth.
-- logistic population growth

**2 modes of population growth**

- **J-shape**, Exponential
- **S-shape**, Logistic
Density-dependent b and d prevent unlimited population growth

Density-dependent birthrate

Density-dependent death rate

Equilibrium population density

High Population density →

Low

High

Death rate

Birthrate

Density-dependent b alone prevents unlimited population growth

Density-dependent birthrate

Density-independent death rate

Equilibrium population density

High Population density →

Low

High

Death rate unchanged
Density-dependent d alone prevents unlimited population growth

Density-dependent birthrate
Density-independent birthrate
Equilibrium population density

Birthrate unchanged
Population density

High Death rate
Low

Density dependent birth & death rates

Number of young per female vs Number of breeding adults
Juvenile mortality

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Density dependent birth rates

(a) Plantain

(b) Song sparrow

Density dependent death rate
A logistic (S-shape) population growth

Exercise: Logistic growth & life histories

- The logistic population growth model predicts different growth rates for different populations, relative to carrying capacity.

- The life history strategies that natural selection favors may vary with population density.

- Should natural selection favor life history that emphasize “quality” or “quantity” of offspring when the population is at carrying capacity?
Life history strategies

- *K*-selection species -- organisms live around $K$, and are sensitive to population density. Thus, tend to produce relatively few offspring, and invest heavily in parental care.

- *r*-selection species -- organisms occur in variable environments in which population densities fluctuate well below $K$. Thus, tend to produce many offspring, and invest little in parental care.

Comparing life history strategies

<table>
<thead>
<tr>
<th>Adaptation</th>
<th><em>r</em>-Selected Populations</th>
<th><em>K</em>-Selected Populations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at first reproduction</td>
<td>Early</td>
<td>Late</td>
</tr>
<tr>
<td>Life span</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>Maturation time</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>Mortality rate</td>
<td>Often high</td>
<td>Usually low</td>
</tr>
<tr>
<td>Number of offspring produced per reproductive episode</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>Number of reproductions per lifetime</td>
<td>Usually one</td>
<td>Often several</td>
</tr>
<tr>
<td>Parental care</td>
<td>None</td>
<td>Often extensive</td>
</tr>
<tr>
<td>Size of offspring or eggs</td>
<td>Small</td>
<td>Large</td>
</tr>
</tbody>
</table>
Exercise: Please give examples of \( K \)-selected, & \( r \)-selected species?
\[ \Delta N = B - D + I - E \]

Immigration and emigration may also affect population growth

---

**Immigration is Important in U.S. Population Growth**

<table>
<thead>
<tr>
<th>IMMIIGRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>with current level of net immigration</td>
</tr>
<tr>
<td>387</td>
</tr>
<tr>
<td>with no net immigration</td>
</tr>
<tr>
<td>307</td>
</tr>
</tbody>
</table>

![Graph showing population growth with and without net immigration](image)
The dynamics of real natural populations

Time (years)

Number of breeding male fur seals (thousands)

Population size (adults)
0 20 40 60 80 100 120 160 200

The dynamics of real natural populations

Number of breeding male fur seals (thousands)

Time (years)
1915 1925 1935 1945

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The dynamics of real natural populations

The dynamics of real natural populations
The dynamics of real natural populations

![Graph showing the number of females over time.](image)

The dynamics of real natural populations

![Graph showing the commercial catch of male crabs over time.](image)
Exercise:

Why don’t most real populations follow logistic (S-shaped) growth?

Age structure

- Other than generation time, age structure is another important factor affecting r.

- Proportion of population at reproductive age (15 to 45 years in human) influences population growth.
Exercise: Which population will grow faster?

Population pyramids

- stable - rectangular
- rapid growth - triangular
- decreasing - inverted pyramid
Which population will grow faster?

![Population Pyramids](image)

World Population Growth: Fastest in Developing Countries

<table>
<thead>
<tr>
<th></th>
<th>United States (highly developed)</th>
<th>Brazil (moderately developed)</th>
<th>Ethiopia (poorly developed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertility rate</td>
<td>2.1</td>
<td>2.2</td>
<td>5.9</td>
</tr>
<tr>
<td>Doubling time at current rate (yr)</td>
<td>115</td>
<td>53</td>
<td>28</td>
</tr>
<tr>
<td>Infant mortality rate (per 1000 births)</td>
<td>6.6</td>
<td>33</td>
<td>97</td>
</tr>
<tr>
<td>Life expectancy at birth (yrs)</td>
<td>77</td>
<td>69</td>
<td>52</td>
</tr>
<tr>
<td>Per capita GNP (U.S.$)</td>
<td>$34,100</td>
<td>$3500</td>
<td>$660</td>
</tr>
<tr>
<td>Population &lt; 15 years old (%)</td>
<td>21</td>
<td>30</td>
<td>44</td>
</tr>
</tbody>
</table>
Exercise:
What is the current world population size & growth rate?
What is the carrying capacity of Earth for humans?

- The second question is difficult to answer. Estimates are usually based on food, but agricultural revolution change assumptions on available food.

- We may never know Earth’s carrying capacity for humans, but we have the unique responsibility to decide our fate and the fate of the rest of the biosphere.
Uncertain future

- Earth’s rapidly growing human population is possibly the greatest challenge facing the biosphere.

- Population growth contributes to pollution, and loss of habitat and species diversity.
Is controlling population growth the way to go?

<table>
<thead>
<tr>
<th>Region</th>
<th>Slogan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henan Province</td>
<td>搶劫警車是違法的!!</td>
</tr>
<tr>
<td>绝对经典的一条</td>
<td>一人独生全家光荣!!</td>
</tr>
<tr>
<td>铁路上看到的</td>
<td>横卧铁轨，死掉也要负上刑责！</td>
</tr>
<tr>
<td>北京某远郊县</td>
<td>少生孩子多种树，少养孩子多养猪！</td>
</tr>
<tr>
<td>山东省看到的标语</td>
<td>光缆不带钢，偷盗要判刑！</td>
</tr>
<tr>
<td>湖南省某县的生育计划标语</td>
<td>谁不实行计划生育，就叫他家破人亡！</td>
</tr>
<tr>
<td>河北省某县的生育计划</td>
<td>宁可家破，不可国亡。</td>
</tr>
<tr>
<td>河南省某县</td>
<td>十座坟，不添一个人。</td>
</tr>
<tr>
<td>火车内</td>
<td>保持车厢清洁，果皮抛出窗外</td>
</tr>
</tbody>
</table>

Is controlling population growth the way to go?
Exercise: Uncertain future

Is controlling population growth the way to go?

Consider this: what is more damaging—population size or per capita impact of that population?

<table>
<thead>
<tr>
<th></th>
<th>Per capita CO₂ emissions (metric tons of carbon)</th>
<th>Total CO₂ emissions (billion metric tons of carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1 2 3 4 5 6</td>
<td>0 0.5 1 1.5</td>
</tr>
<tr>
<td>U.S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>0.75</td>
<td>1.49</td>
</tr>
<tr>
<td>Russia</td>
<td>2.65</td>
<td>0.91</td>
</tr>
<tr>
<td>Japan</td>
<td>2.51</td>
<td>0.39</td>
</tr>
<tr>
<td>India</td>
<td>0.29</td>
<td>0.32</td>
</tr>
</tbody>
</table>

impact population size
CO₂ may cause global warming—Is U.S. responsible for it?

<table>
<thead>
<tr>
<th>Country</th>
<th>Per capita CO₂ emissions (metric tons of carbon)</th>
<th>Total CO₂ emissions (billion metric tons of carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>0.29</td>
<td>5.48</td>
</tr>
<tr>
<td>China</td>
<td>0.75</td>
<td>1.45</td>
</tr>
<tr>
<td>Russia</td>
<td>2.65</td>
<td>0.39</td>
</tr>
<tr>
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<td>2.51</td>
<td>0.32</td>
</tr>
<tr>
<td>India</td>
<td>0.29</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Ecological Footprints

<table>
<thead>
<tr>
<th>Country</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>30.2</td>
</tr>
<tr>
<td>Germany</td>
<td>15.6</td>
</tr>
<tr>
<td>Brazil</td>
<td>6.4</td>
</tr>
<tr>
<td>Indonesia</td>
<td>3.7</td>
</tr>
<tr>
<td>Nigeria</td>
<td>3.2</td>
</tr>
<tr>
<td>India</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Amount of land required to support an individual at standard of living of population.
Do you know your “ecological footprints?”

http://www.lead.org/leadnet/footprint/intro.htm